# Importance of Thin Plankton Layers in Hawaiian Food Web Interactions: Research Spanning From Physical Circulation to Spinner Dolphins

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## LONG-TERM GOALS

Our long-term goal is to develop the capability to predict the occurrence and consequences of *layer structure and biological aggregations* in coastal waters.

## OBJECTIVES

***Our goals are*** (1) to quantify layered aggregations of the *phytoplankton, zooplankton, and the nearshore sound-scattering layer* around Hawaii, (2) to identify the physical, optical, and acoustical characteristics associated with these aggregations, (3) to assess the horizontal scales of coherence between these various levels of biological aggregations and understand their interactions, (4) to assess the impact of these layers on optical and acoustical measurements in the nearshore environment, (5) to determine the effects of thin layers on spinner dolphins.

## APPROACH

This project takes an interdisciplinary approach to look at the relationships between the distribution of phytoplankton, zooplankton, mesopelagic micronekton, and spinner dolphins along with acoustical and optical scattering from these organisms and the topography and physical circulation patterns of the study region. We combine moored and expeditionary approaches to determine the predictors of organismal distribution and the relationship between various groups. The system presents a unique opportunity to look at how the organisms in Hawaii's nearshore waters aggregate and disassemble as

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**Our long-term goal is to develop the capability to predict the occurrence and consequences of layer structure and biological aggregations in coastal waters.**

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many of the biological mechanisms are regulated on a diel cycle as a response to light levels. The study area extended west of the leeward coast of Oahu, Hawaii in the area of 21° 30.5' N, 158° 14.2'W. This area was chosen because of the high abundance of spinner dolphins, the presence of dense aggregations of thin layers and micronekton. Key individuals participating in this work are Dr. Kelly Benoit-Bird (PI), Dr. Margaret McManus (PI), Mr. Chad Waluk, and Mr. Jeff Sevadjian. Dr. Benoit-Bird is recognized for her research, which uses a variety of acoustic and optical techniques to understand pelagic animal dynamics. Dr. McManus is recognized for her work assessing the interactions of biological and physical processes in the coastal ocean. Mr. Chad Waluk is the lead oceanographic technician in the Benoit-Bird Laboratory at Oregon State University. Mr. Jeff Sevadjian is the lead oceanographic technician in the McManus Laboratory at the University of Hawaii at Manoa. We are grateful for the contributions of both Mr. Waluk and Mr. Sevadjian, in addition to the numerous, good-natured volunteers who joined us this field season.

## WORK COMPLETED

**Mooring Array.** For approximately 3 weeks (20 April and 11 May) in 2009, a series of moorings were deployed to assess the biological and physical features off Oahu's leeward coast in addition to the optical and acoustical characteristics of the water column. On 20 April 2009, we deployed a series of moored, upward looking 200 kHz echosounders (*bioacoustic moorings*) to characterize the distribution and movement of zooplankton and micronekton aggregations. The bioacoustic moorings sample every 4 seconds with a vertical resolution of at least 10 cm. Single frequency bioacoustic moorings were deployed across slope at the 20 and 40 m isobaths with a 3-frequency system moored at the 25 m isobath. These moorings provided information on the depth and intensity of sound-scattering layers over time. This is allowing us to investigate the movement patterns of the layers across the island's slope as well as the variability in the layer within and between nights. In addition, the three-frequency mooring at 25 m allows for inversion approaches to be used to size and identify to shape class-detected zooplankton. An array of thermistor chains was deployed across slope in concert with the bioacoustic moorings (10, 20, 25 and 40 m isobaths). The thermistor chains measure temperature at fixed depths throughout the water column, every 30 s. Information from the array of thermistor chains, coupled with salinity measurements at the 40 m site, are allowing us to investigate the passage of ocean eddies and fronts, internal tidal energy and vertical water column structure (after McManus et al. in 2008). One autonomous profiler was deployed at the 25 m site. The autonomous profiler (the Seahorse; Brooke Ocean Technology) used wave energy to power extended, high-resolution profiling of water properties. The instrument was moored to the seafloor and was left to collect samples autonomously. A SeaBird SBE-19 CTD on the profiler measured temperature, salinity, pressure, and oxygen. A WET Labs Inc. ECO-FLS fluorometer on the profiler measured chlorophyll fluorescence. The fluorescence values are being converted to chlorophyll a, which is a bulk measurement of phytoplankton biomass. Thus, the autonomous profiler provided measurements of phytoplankton biomass, every 30 minutes, throughout the entire water column over a 3-week period. High-resolution vertical profiles were collected every half-hour between the bottom and the surface at an average ascent rate of 8 cm $s^{-1}$. Between profiles, the sensor package was held stationary at the bottom until the next sampling interval. Information from the autonomous profiler is allowing us to investigate the passage of ocean eddies and fronts, changes in tidal energy, fine scale, vertical water column structure, Thorpe displacement scales (Thorpe, 1977) and heat loss/gain. Data from the autonomous profiler were telemetered back to shore every half-hour and made available on the www in near-real time. A bottom-mounted ADCP was deployed at the 25 m site to measure full water column current patterns in the absence of the scattering layer. Previous attempts to utilize an acoustic Doppler current profiler (ADCP) during the layer's migration (night time hours) have had limited success because of high scattering from the rapidly moving mesopelagic micronekton (Benoit-Bird et al., 2001). Consequently, in the past only currents between mesopelagic patches or above the mesopelagic layer could be measured. Thus, in addition to the bottom-mounted ADCP, Nortek current meters were deployed at the mean depth of the scattering layer on the thermistor chains at the 10 and 20 m sites. Each Nortek current meter measured current speed and direction at 2 min resolution. One weather station was deployed onshore in direct alignment with the array. Information from the weather station is allowing us to investigate wind driven flow and heat loss/gain in the system. The weather station measured local wind magnitude and direction, as well as air temperature and barometric pressure every 15 minutes.

**Ship Board Surveys**. To further characterize the location of the sound-scattering layer, thin layers, spinner dolphins, hydrography and optical properties in 3-dimensions; we used a small vessel (31 ft) to conduct ship surveys and 24 hour continuous profiles. During the ship board surveys, we continuously measured current magnitude and direction with a downward-looking 600 kHz acoustic Doppler current profiler (ADCP), with a vertical resolution of 1 m. Vertical shear is being calculated after Itsweire et al. (1989). A five-frequency (38, 70, 120, 200, 710 kHz) echosounder system was used to characterize the broader spatial distribution of the scattering layer and zooplankton from shipboard. This data is being compared with the results from the moorings to determine how predictable patches within the sound-scattering layer are, and if patches are correlated with specific locations. A 200 kHz multibeam sonar was used to measure the fine-scale habitat use of spinner dolphins in three-dimensions. The multibeam system uses a 150 ms long outgoing pulse transmitted at a rate of 5.6 per second. The system has a resolution of 0.12 m depth resolution. The system has 120, 1.5 º x 20º beams that overlap by 0.25º in the across-track direction, providing an angular coverage 120 º with 1º. Data were taken using the external imaging transducer of the sonar, thus forming a Mills Cross to provide the greatest spatial resolution, giving a received beam width of 1.5º along-track. Further technical details about the sonar can be found in Cochrane et al. (2003). A high resolution profiling package (SLO-DROP, descent rates 8-10 cm/s) was outfitted with a low-light camera system to identify micronekton and estimate its size (Benoit-Bird and Au, 2006), an optical plankton counter (CTD) and a Tracor acoustic profiling system (TAPS) to assess zooplankton abundance and vertical structure, a fluorometer to determine the optical signature of the water column, an a WET Labs Inc. ac-9 to measure total absorption and attenuation of light at nine wavelengths between 412 and 715 nm, a SBE 25 CTD to determine conductivity, temperature, and depth and a PAR sensor to measure photosynthetically available radiation. This high-resolution profiling package provided a spatial rendering distribution of the micronekton, zooplankton, and fluorescence and physical hydrography. A 0.5-m diameter opening/closing net was used to collect samples of zooplankton inside and outside of vertically stratified aggregations, permitting assessment of the size, density, and identity of zooplankton.

**24-Hour Stations** In total, three, 24-hour ship board surveys were undertaken in synch with the phases of the moon (25-26 April, new moon: 2-3 May, half moon: 9-10 May, full moon) involving near-continuous (every 4 minutes) profiling with the shipboard profiler were conducted at the 25 m isobath. These observations are allowing us to look at the temporal patterns of thin layers of phytoplankton and zooplankton as grazing pressure changes. Note: All instruments were successfully recovered from the study site on 11 May 2009 with no negative effect to the environment.

**Data Analyses**. Data were recovered from all instruments deployed in the study region. The first stage of processing took place between 12 May and 1 September 2009: All data time series were synched to within a second. Where appropriate, data sets were calibrated. In the case of the profilers, all data were correctly lagged. All data have been 'quick'-plotted and posted to our group's internal web page. We are now in our second stage of processing, 2 September – present. We are in the process of (1) quantifying layered aggregations of the phytoplankton, zooplankton, and the nearshore sound-scattering layer, (2) identifying the physical, optical, and acoustical characteristics associated with these aggregations, (3) assessing the horizontal scales of coherence between these various levels of biological aggregations and understand their interactions, (4) assessing the impact of these layers on optical and acoustical measurements in the nearshore environment, (5) determining the effects of thin layers on spinner dolphins.

## RESULTS

**General flow patterns** along the western coast of Oahu are dominated by both surface and internal tidal forcing. Daily depth-averaged currents were oriented parallel to shore (north to south) 75% of the time (McManus et al. 2008). We observed periodic rapid decreases in bottom water temperature of up to 0.3°C and subsequent enhancements of nitrate in near-bottom waters. These cold pulses appeared to be associated with onshore movement of water caused by the internal tide generated at the Kaena Ridge, which is located northwest of the island of Oahu. Stratification in coastal Hawaiian waters was low relative to other mainland US coastal regions where thin layers have been observed (Dekshenieks et al. 2001, Ryan et al. 2008, Sevadjian et al. submitted).

**Thin Layers.** Forty-eight layers of fluorescence were observed during the three-week deployment. These layers were observed at an average depth of 12 m (of a 20 m water column). The average layer thickness was 1.9 m. Seventy-one layers of decreased light transmission were observed during the three-week deployment. These layers were observed at an average depth of 10 m. The average layer thickness was 66 cm. One hundred and seventy seven thin layers of increased acoustic scattering attributable to zooplankton were observed during the deployment. These layers were observed at an average depth of 13 m with an average layer thickness of 1.8 m. For all layer types, there was a dramatic change in their detection rates at the same time period approximately halfway through the study period that was concomminant with a change in water mass type in the study area.

**Deep-scattering layer.** The intensity of acoustic scattering from the mesopelagic sound-scattering layer at 25 m showed a strong diel pattern as expected. The overall intensity of scattering from this layer and the contrast in total scattering between day and night increased throughout the study period.

**Spinner dolphins.** A total of 6390 acoustic targets consistent with spinner dolphins were detected over the 25 m mooring. A strong diel pattern in abundance and mean depth of individual dolphins was observed, with the most dolphins in the area between 0000 h and 0200 h local time. The frequency of dolphin detections varied considerably over the study period with more than 700 dolphin detections in some days early in the experiment with less than 100 dolphin detections in days near the end of the experiment. This change occurred at approximately the same time as the shift in the detection rate of thin plankton layers.

## IMPACT/APPLICATIONS

This research combines work in acoustics, optics, and physical oceanography to understand the role thin plankton layers play in structuring trophic interactions in Hawaii's nearshore ecosystem. This understanding of predators' use of thin layers will provide insight into the processes driving the formation, maintenance, and dissipation of thin layers of both phytoplankton and zooplankton. It will also permit us to look at the indirect effects of zooplankton thin layers on the foraging behavior of spinner dolphins through effects on their micronekton prey. We are addressing the relationship between these significant biological sources of scattering and the acoustical, optical, and physical characteristics of the water column. We are determining which physical and biological measures can be used to make predictions about the distribution of phytoplankton, zooplankton, micronekton, and spinner dolphins. The ability to predict biological sources of scattering will provide significant information for the interpretation of tactical acoustic and optical instruments. In addition, management of marine mammal species and mitigation of human impacts on dolphin populations must be done with an understanding of the ecosystem forces driving their behavior. This work takes an unprecedented look at the fine scale, subsurface ecology of dolphins along with a detailed examination of their physical and biological environment, providing substantial information to guide mitigation efforts. This is the first fully integrated ecosystem study of thin layers and their ecological significance.

## RELATED PROJECTS

*Funding Agency:* Office of Naval Research
*Project Title:* Quantification of the Interacting Physical, Biological, Optical and Chemical Properties of Thin Layers in the Sea
*Project Period:* 02/2004-12/2009
*Principal Investigators:* PI Margaret McManus (UH); Co-PIs John Ryan (MBARI), Mark Stacey (Berkeley)

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**HONORS/AWARDS/PRIZES**

Margaret McManus, University of Hawaii at Manoa,

- Aldo Leopold Fellow, 2006
- Promotion to Associate Professor with Tenure, 2007
- Kavli Frontiers Fellow, National Academy of Sciences, 2009

Kelly Benoit-Bird, Oregon State University

- Kavli Frontiers Fellow, National Academy of Sciences, 2006
- Presidential Early Career Award for Scientists and Engineers, 2006
- Ocean Sciences Early Career Award, American Geophysical Union, 2008 “for innovative application of acoustical techniques”
- Promotion to Associate Professor, 2009
- R. Bruce Lindsay Award, Acoustical Society of America, 2009 “For contributions to marine ecological acoustics”